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Space Administration

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This report is a formal draft or working paper, intended to solicit comments and ideas from a technical peer group.

This report contains preliminary findings, subject to revision as analysis proceeds.

Note that at the time of research, the NASA Lewis Research Center was undergoing a name change to the NASA John H. Glenn Research Center at Lewis Field. Both names may appear in this report.

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THE EFFECT OF TUNGSTEN AND NIOBIUM ADDITIONS ON DISK ALLOY CH98

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INTRODUCTION

Gas turbine engines for future subsonic transports will probably have higher pressure ratios which will require nickel-base superalloy disks with 1300F to 1400F temperature capability. Several advanced disk alloys are being developed to fill this need. One of these, CH98, is a promising candidate for gas turbine engines and is being studied in NASA's AST Program. For AST applications, compressor/turbine disks must withstand temperatures of 1300F for several hundred hours over the life of the engine. Additions of the refractory elements tungsten and niobium to CH98 could improve tensile and creep properties, however, the impact on high temperature fatigue crack growth is uncertain. In this paper, these three key properties, tensile, 0.2% creep, and fatigue crack growth, of CH98 with and without tungsten and niobium additions will be assessed at 1300F.

MATERIAL & TEST PROCEDURE

CH98 is a nickel-base superalloy, with a gamma prime content of about 60%. The compositions of experimental heats of CH98 and CH98 with tungsten and niobium additions (CH98 + W & Nb) are shown in Table 1. The levels of these two alloying additions are based on suggestions from PWA and GEAE. These alloying additions are believed to have a slight impact on gamma prime content and the solvus, increasing the gamma prime content and reducing the solvus (Ref. 1). Both alloys were produced from argon atomized powder by hot compaction at 1925F followed by extrusion at 1965F with an 8:1 reduction ratio. Specimen blanks were cut from the extrusions (longitudinal orientation) and HIPed at 2200F/30KSI/3HR to achieve an ASTM 6-8 grain size without excessive porosity. These blanks were then solution heat treated at 2170F/2HR in a vacuum furnace and quenched with an initial cooling rate of 60F/MIN, and aged at 1400F/8HR. The solution temperature was set close to the estimated solvus of CH98. Some of the blanks were also stabilized at 1550F/2HR before aging. The stabilization treatment is employed to reduce residual stress levels and thereby improve machinability. In addition, stabilization precipitates $M_{23}C_6$ carbides and tends to increase the size of the gamma prime precipitates, particularly the aging gamma prime. Photomicrographs of the two alloys are presented in Figure 1. The presence of micron sized gamma prime indicates both alloys were solutioned below their solvus temperatures. However, the presence of less micron size gamma prime in CH98 + W & Nb indicates its solvus is indeed lower than CH98. The grain size of the CH98 + W & Nb was also slightly larger, ASTM 7.5, than CH98, ASTM 8.5.

Tensile, creep and crack growth specimens were machined from the heat treated blanks. The tensile and creep specimens were identical with a cylindrical gage section measuring 0.160" in diameter by 0.750" long. Tensile tests were run at 1300F at a strain rate of 0.5%/minute through yield. Creep tests were run at 1300F and 90KSI. Crack growth rates were measured using a K_B Bar test developed by Vanstone (Ref. 2). The K_B Bar had a rectangular cross section measuring 0.40" wide and 0.17" thick with a thin, semicircular surface flaw 0.015" in diameter located at the center of the 0.40" face. A precrack extending to a depth of about 0.030" (0.015" notch plus 0.015" crack) was introduced by high frequency cycling at room temperature before dwell testing at 1300F. The peak load for precracking and testing was held constant throughout at a stress level of about 100KSI. A tension-tension dwell cycle was employed during testing at 1300F with a 180 second dwell at peak load and an R-ratio of 0.1. Dwell crack growth rates were monitored using a DC potential drop technique from a K_{MAX} of 20 to 40KSI-IN$^{0.5}$ producing two distinct calibration points per test.

RESULTS & DISCUSSION

The 1300F tensile data for both alloys is presented in Figure 2 and Table 2. Yield strength of CH98 + W & Nb was 136KSI, while that of CH98 was about 125KSI. Ultimate strength showed a similar trend, with CH98 + W & Nb falling in the 170 to 180KSI range and the CH98 falling in the 160 to 170KSI range. Stabilization tended to depress strength for both alloys, but the impact was generally less than 2%. Ductility was greater than 25% elongation and 25% reduction in area, for all alloys and heat treatments.

Creep data CH98 was generated at 1300F/90KSI, as previously stated. The time to 0.2% creep, an important design consideration for disk operation, is presented in Figure 3. Regardless of heat treatment, tungsten and niobium additions are seen to have a beneficial effect on creep. A significant difference in the creep resistance is evident, with CH98 + W & Nb showing about 400 hours to 0.2% creep, while the stabilized CH98 had 0.2% creep times less than 100 hours. As in previous studies (Ref. 3), stabilization decreases time to 0.2% creep for CH98 by about a factor of three. However, CH98 + W & Nb shows no deleterious effect from stabilization at 1550F/2HR. These results were repeated and the individual data are presented in Table 3. This finding is very significant, provided the stabilization heat treatment has also reduced the residual stress levels to a satisfactory extent.

The beneficial effect of tungsten and niobium additions on CH98 creep are believed to be primarily related to alloying effects and not microstructural effects. The differences in grain size, ASTM 7.5 versus ASTM 8.5, and gamma prime distribution, Figure 1, and their effects on creep were investigated by solution heat treating CH98 at a variety of temperatures. These specimens were solution heat treated between 2025 and 2200F, stabilized and aged. This produced microstructures with micron sized gamma prime area fractions between 0 and about 40% and grain sizes between ASTM 8 and 10, Figure 4. The results of these creep tests are plotted in Figure 5 along with the data for stabilized CH98 + W & Nb. These data show the time to 0.2% creep for all microstructural variants of CH98 was significantly less than 400 hours and could not fully account for the increased 0.2% creep time of CH98 + W & Nb. While microstructural changes associated with alloying additions are probably contributing to the beneficial effect of tungsten and niobium additions, it would appear that the presence of tungsten and niobium additions alone or in combination are required to obtain the optimal creep performance in alloys like CH98.

The 1300F dwell crack growth rates of CH98 and CH98 + W & Nb were measured and are compared in Figure 6 for the direct age condition. As seen in this plot, both alloys have comparable dwell crack growth rates. This result is encouraging as niobium additions have been suspected to have a detrimental effect on crack growth (Ref. 4). The mode of crack growth was primarily intergranular, Figure 7, in both cases. Stabilization was found to be beneficial to dwell crack growth for CH98, with about a five fold decrease in crack growth rate. Due to material limitations at this time, crack growth testing on stabilized CH98 + W & Nb was not run. While stabilization decreased the crack growth rate of CH98, further testing on CH98 + W & Nb is warranted as other alloys, such as Allied Signal's Alloy 10 which contains tungsten and niobium (Ref. 3), show stabilization can reduce dwell crack growth resistance .

SUMMARY & CONCLUSIONS

Key properties of tensile, 0.2% creep, and dwell fatigue crack growth were measured at 1300F for advanced turbine disk alloys, CH98 and CH98 + W & Nb. Both alloys were assessed with a direct age heat treatment, 1400F/8HR, and a stabilization heat treatment, 1550F/2HR & 1400F/8HR. With either heat treatment the tensile and creep properties of CH98 + W & Nb were clearly superior. As with other disk alloys, stabilization was found to degrade the 0.2% creep time of CH98. However, stabilization did not degrade the 0.2% creep time of CH98 + W & Nb. Finally, the fatigue crack growth rates of both alloys were essentially equivalent.

The tensile and creep properties would appear to favor the selection of CH98 with tungsten and niobium additions for disks, especially for applications that require a stabilization heat treatment to improve machinability.

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4. Gao, M., Dwyer, D. J. and Wei, R. P., Chemical and Microstructural Aspects of Creep Crack Growth in IN718, Superalloys 718, 625, 706 and Various Derivatives, TMS, 1994, pp. 581-592.

Table 1. Alloy Composition (W/O)											
ALLOY	Co	Cr	Al	Ti	Mo	Ta	W	Nb	C	B	Zr
CH98	17.90	11.60	3.90	4.00	2.90	2.90	0.00	0.00	0.049	0.030	0.050
CH98+W&Nb	18.30	11.30	3.90	3.80	2.90	2.20	2.30	1.00	0.050	0.030	0.045

Table 2. Tensile Properties					
ALLOY	STABILIZATION	0.2% YIELD	UTS	ELONG	R of A
CH98	NONE	126KSI	166KSI	28%	32%
CH98	1550F/2HR	123	162	27	32
CH98+W&Nb	NONE	136	179	26	27
CH98+W&Nb	1550F/2HR	136	174	32	33

Table 3. Creep Data		
ALLOY	STABILIZATION	0.2% CREEP
CH98	NONE	167 HOURS
CH98	NONE	235
CH98	1550F/2HR	83
CH98	1550F/2HR	66
CH98+W&Nb	NONE	405
CH98+W&Nb	NONE	398
CH98+W&Nb	1550F/2HR	419
CH98+W&Nb	1550F/2HR	452

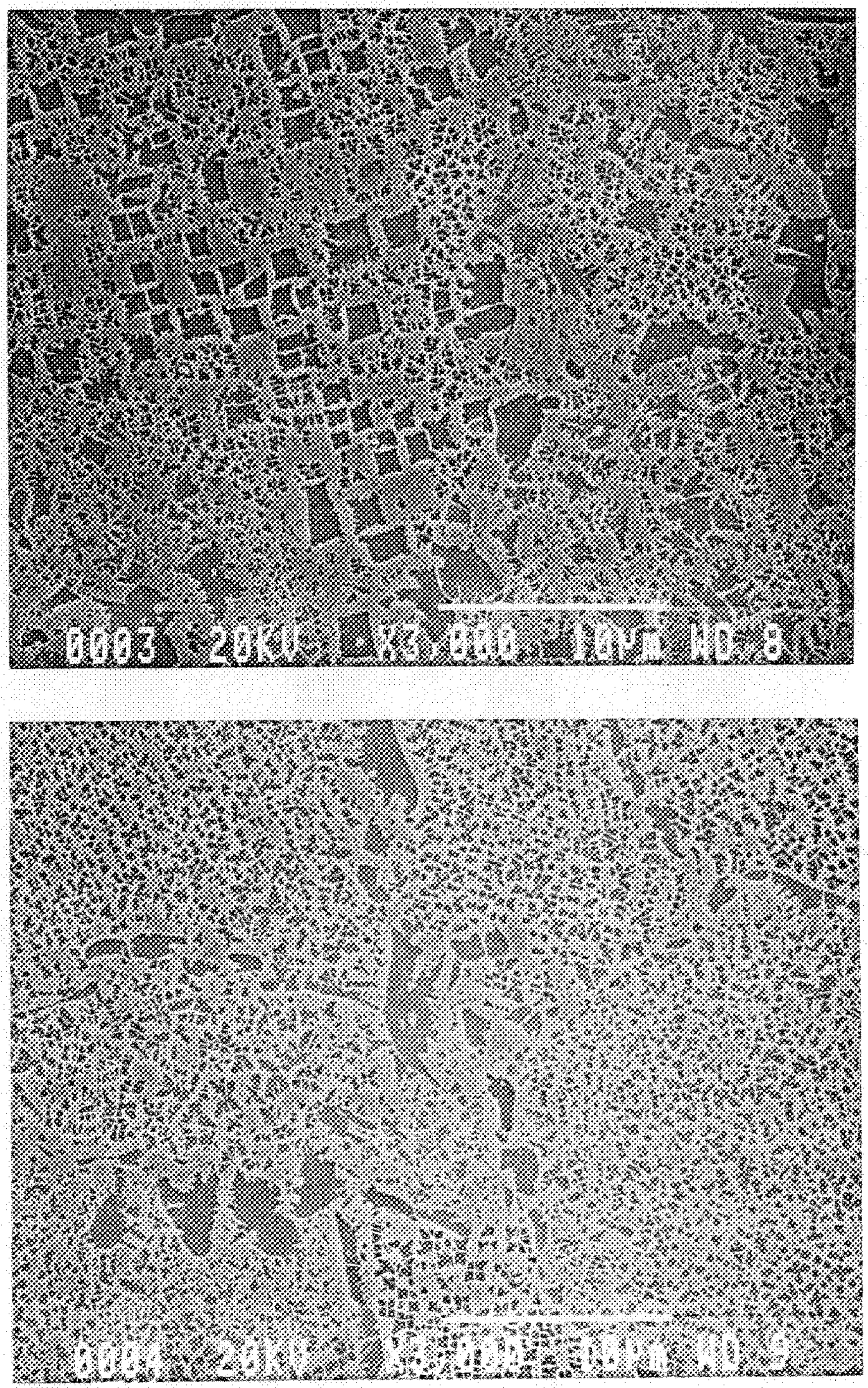

Fig. 1. Microstructures of CH98 (Top) and CH98+W&Nb (Bottom).

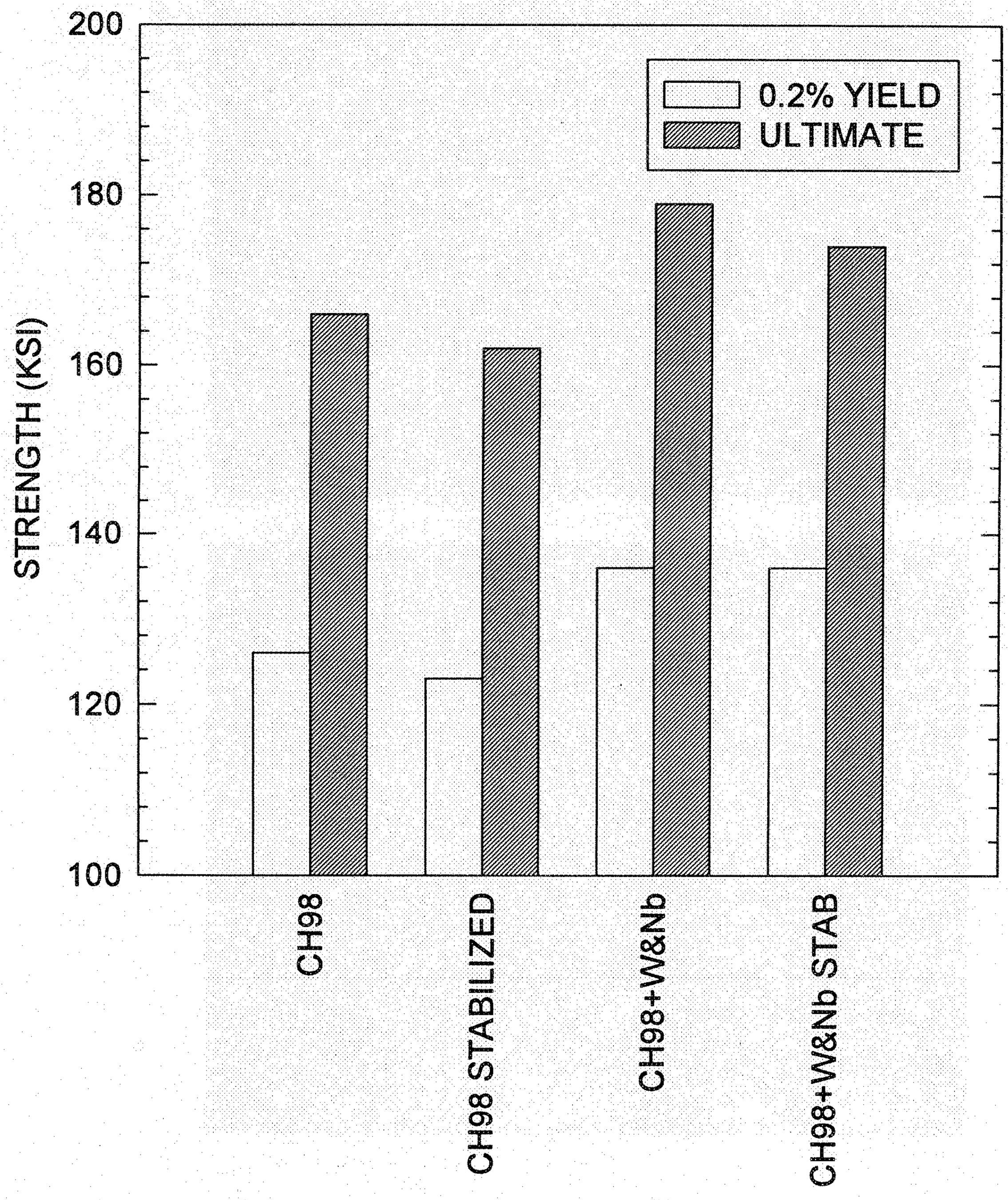

Fig. 2. Yield and ultimate strength of CH98.

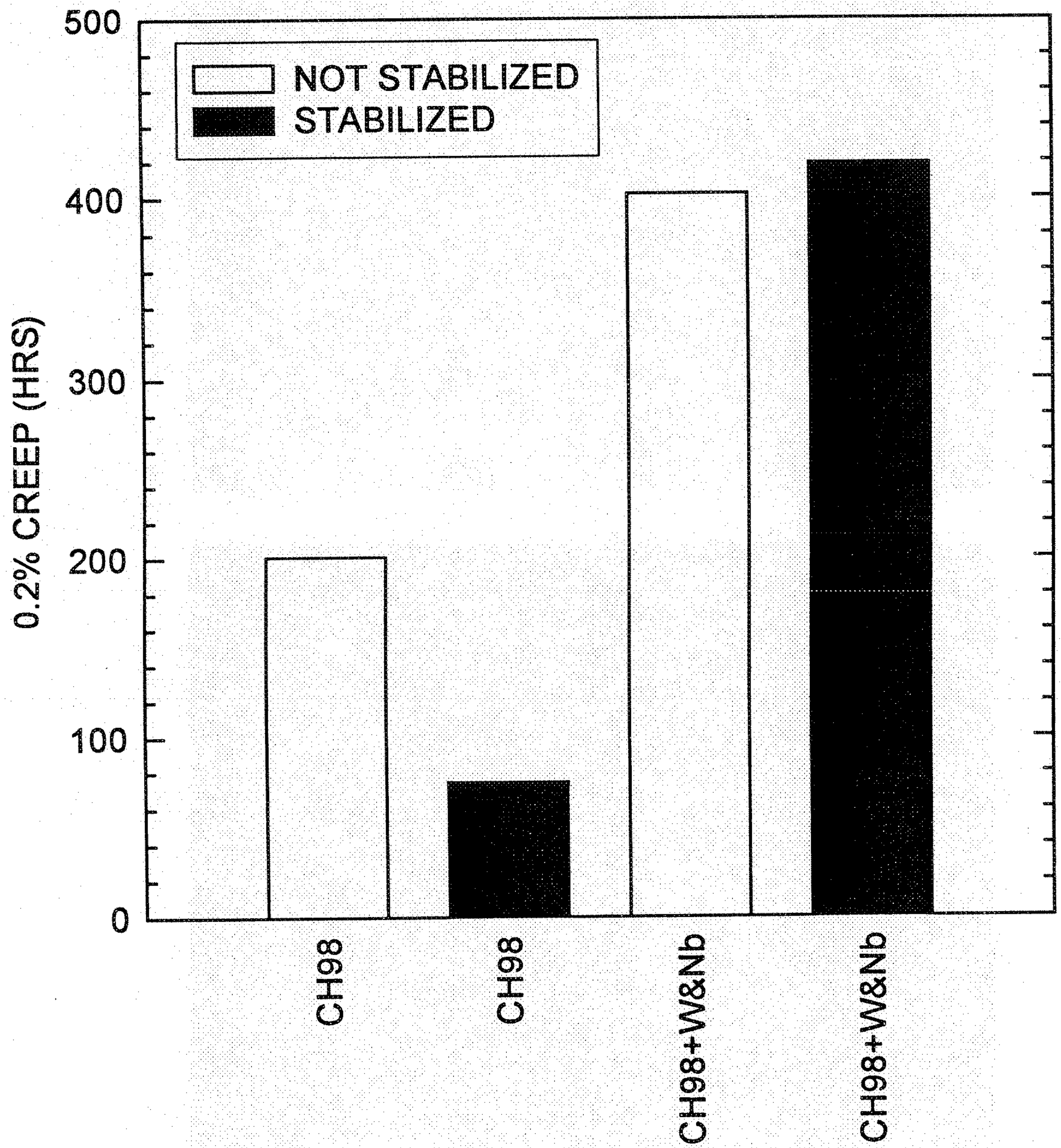

Fig. 3. The effect of tungsten and niobium additions on creep rates of CH98.

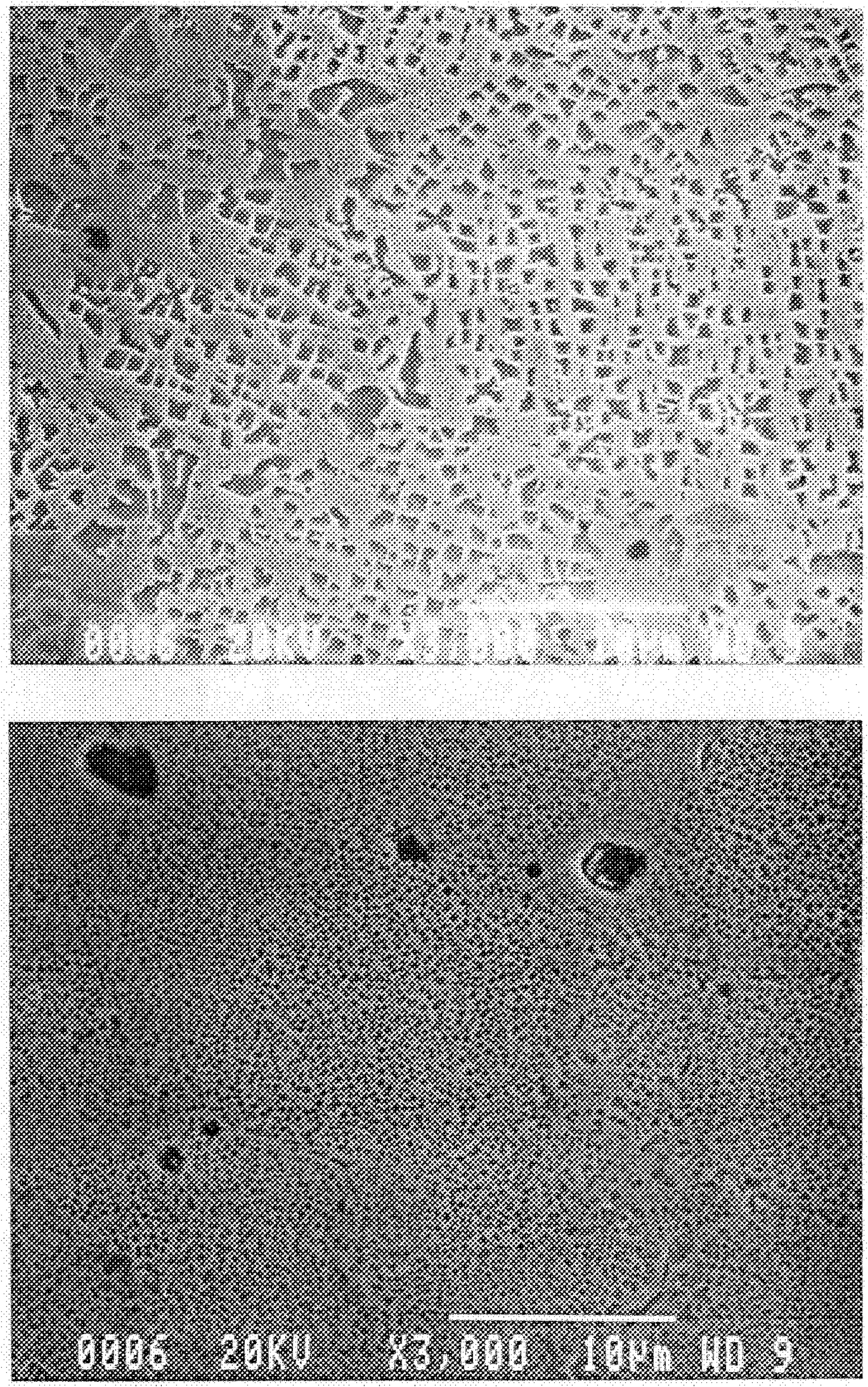

Fig. 4. Gamma Prime distribution in CH98 solutioned at 2025F (Top) and 2200F (Bottom).

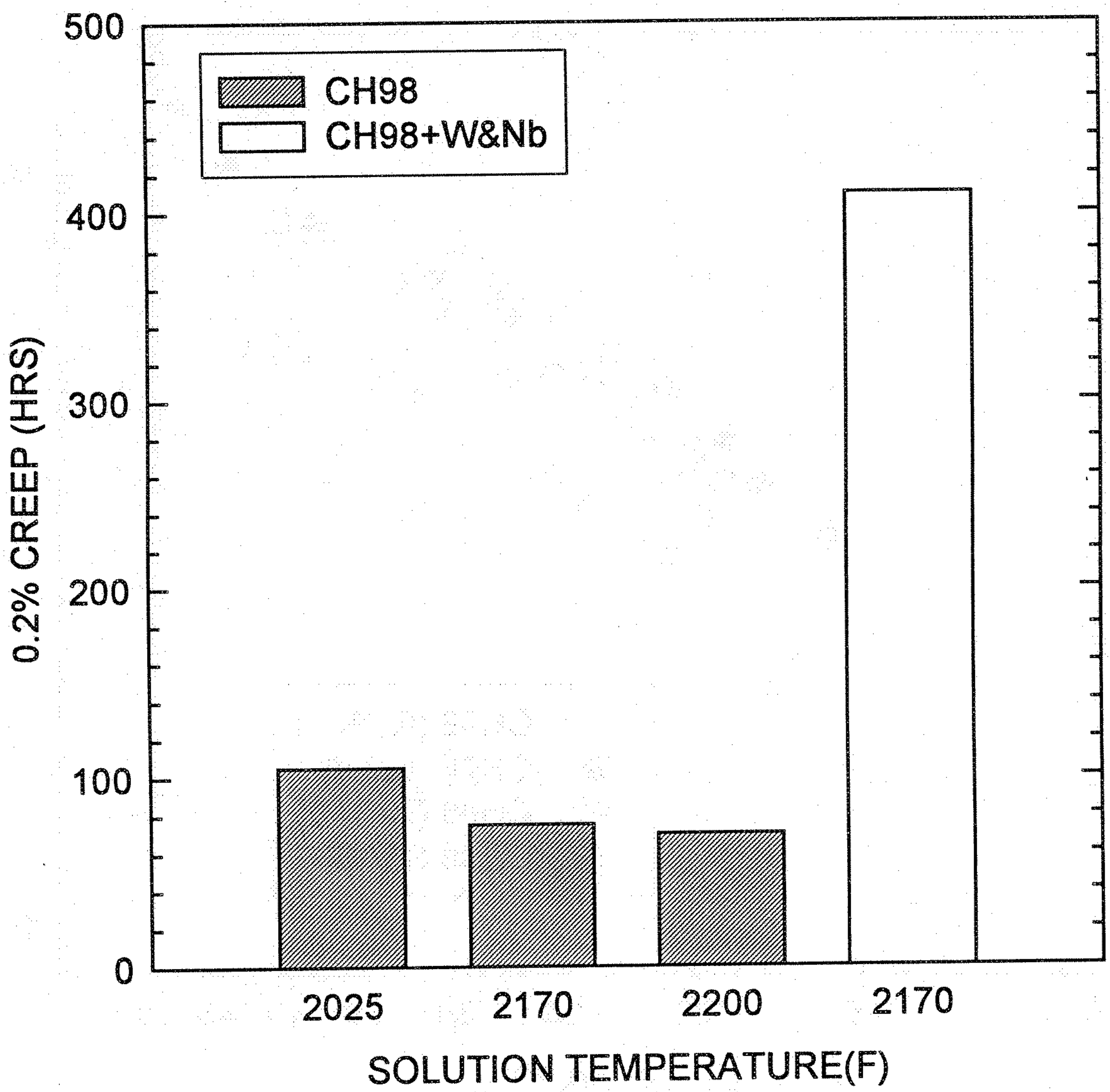

Fig. 5. The effect of solution temperature on creep at 1300F/90KSI.

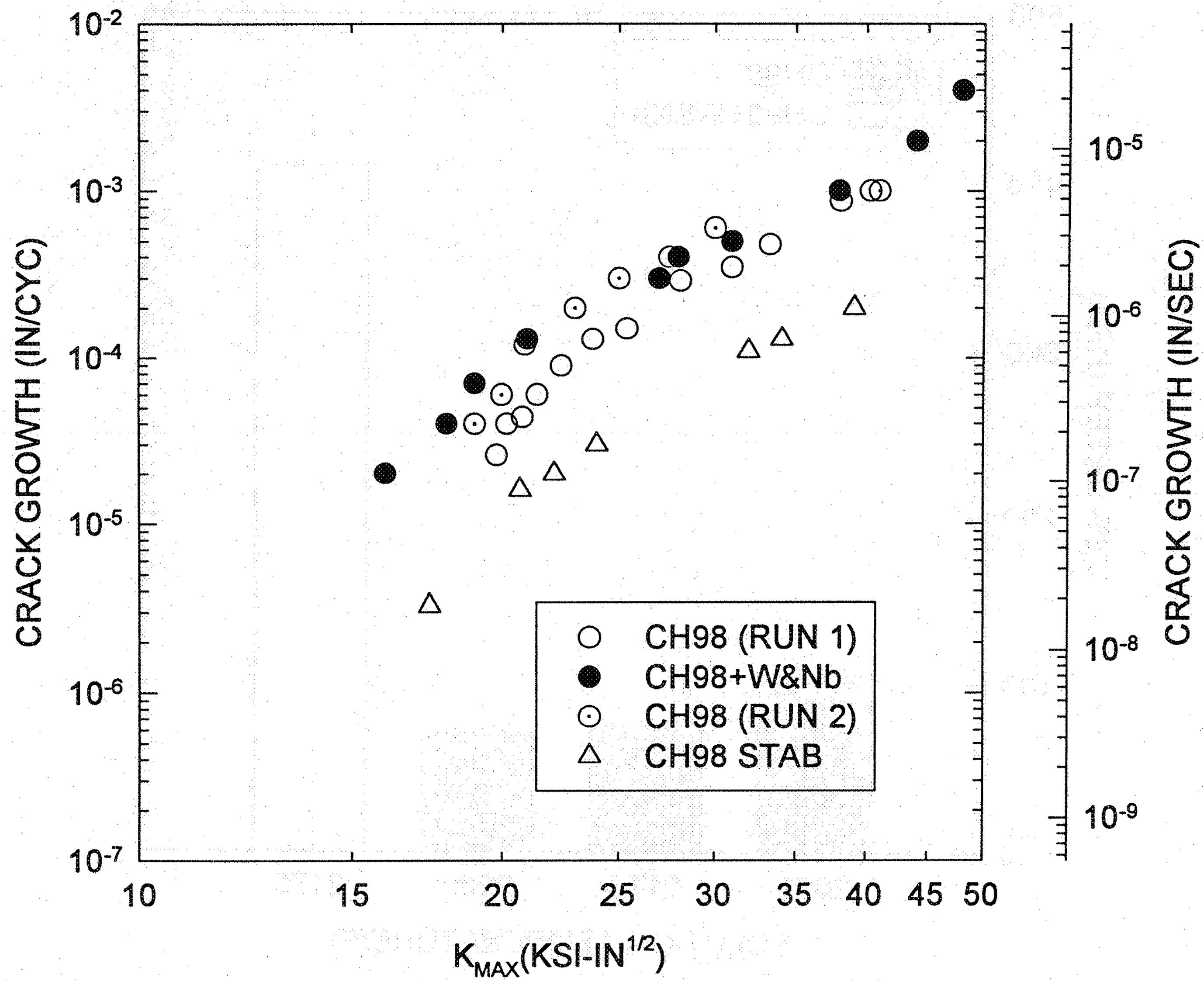

Fig. 6. Fatigue crack growth rates of CH98.

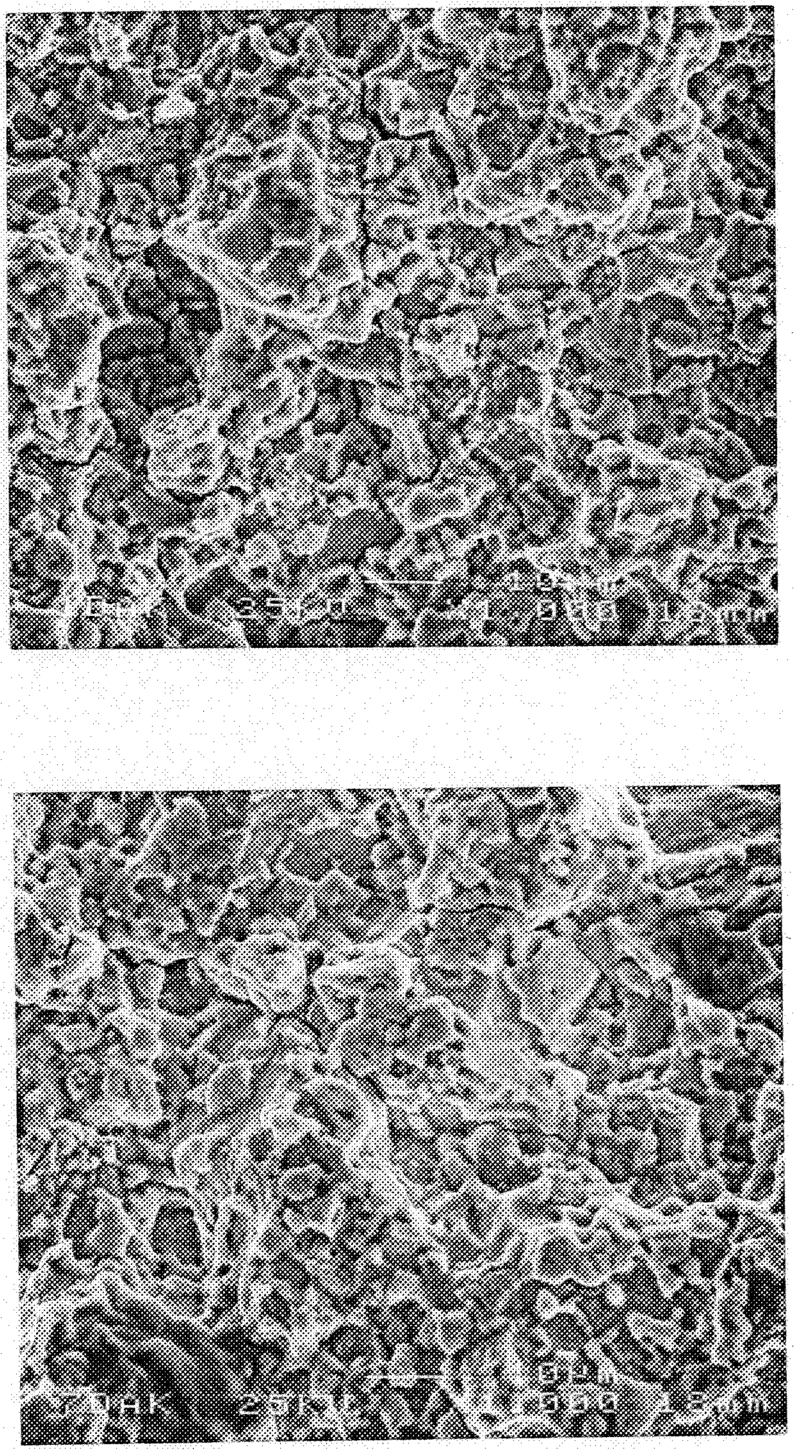

Fig. 7. Fracture surface of CH98 (Top) and CH98+W&Nb (Bottom) crack growth specimens.

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13. ABSTRACT ***(Maximum 200 words)***

Gas turbine engines for future subsonic transports will probably have higher pressure ratios which will require nickel-base superalloy disks with 1300 °F to 1400 °F temperature capability. Several advanced disk alloys are being developed to fill this need. One of these, CH98, is a promising candidate for gas turbine engines and is being studied in NASA's AST Program. For AST applications, compressor/turbine disks must withstand temperatures of 1300 °F for several hundred hours over the life of the engine. Additions of the refractory elements tungsten and niobium to CH98 could improve tensile and creep properties, however, the impact on high temperature fatigue crack growth is uncertain. In this paper, these three key properties, tensile, 0.2 percent creep, and fatigue crack growth of CH98 with and without tungsten and niobium additions will be assessed at l300 °F.

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